HTML ABSTRACT + LINKS

GRB 010921: Discovery of the First HETE Afterglow

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Abstract. We present the discovery of the optical and radio afterglow of GRB 010921, the first gamma-ray burst afterglow to be found from a localisation by the High Energy Transient Explorer satellite. Discovery of the afterglow enabled us to determine the redshift, $z = 0.45092$ from the host galaxy. We expect that the low redshift of this GRB will enable the strongest limits on the detection of an underlying supernova to be made with HST.

DISCOVERY OF THE AFTERGLOW

GRB 010921 triggered the FREGATE instrument on board HETE-2 on 2001 September 21.21934 UT as HETE trigger number 1761. The GRB was detected by only one of HETE's two Wide-field X-ray Monitors, and so localisation was only possible in a single dimension. Localisation in the second dimension was done by the Inter-Planetary Network, and the resultant 250-square-arcmin error box was reported to the community fourteen hours after the GRB through the GRB Coordinate Network (GCN) Circulars [5].

We observed the error box with the Large Format Camera (LFC) on the Hale 200-inch telescope at Palomar Observatory, commencing 22 hours after the GRB [3] in Sloan r'. Even with LFC's 26-arcmin diameter field-of-view, three pointings were required to cover the entire error box. A quick comparison of the images with the DPOSS did not identify the afterglow within the large error box. Hoping to identify the afterglow by its variability, we re-observed the error box with LFC five days later.

Reduction of data from LFC is complicated by the large field-of-view of the instrument which leads to optical distortions in the focal plane, some of which can be removed in software, but coma at the edges of the field is unavoidable. We employed on-chip binning to reduce the file size of the images, but which also lowers the dynamic range of the images, making image comparison and photometry difficult. Comparison of the first- and second-epoch images was done through PSF-matched image subtraction [1]. Despite a subtraction that was imperfect due to the aforementioned problems, we identified two sources within the error box which were clearly variable.

In order to distinguish between the afterglow and a variable star, we re-observed the field 21 and 26 days after the GRB respectively. Photometry from these epochs revealed that one of the previously-identified variable sources had increased in brightness, while the other had faded further and appeared to be settling to a constant flux level, reminscent of the behaviour of other optical afterglows.

We observed the field with the Very Large Array (VLA[1]) 26 days after the GRB, followed by several observations over the course of the following weeks. We identified in the first epoch a radio source at coordinates $22^{h}55^{m}59^{s}931 \pm 0.018$, $40°55'52''23 \pm 0.20$ (J2000), coincident with the optical afterglow candidate, with a spectral slope of $\beta = 0.35 \pm 0.19$ between 4.86 and 22.5 GHz. This value is consistent with that expected from the synchrotron emission of an afterglow ($\beta = 1/3$; Sari, Piran & Narayan [9]). Further observations indicate variability in the source, which is readily interpreted as due to interstellar scintillation, a phenomenon commonly seen in radio afterglows.

The $(B-V)$ and $(R-I)$ colours at 2001 September 22 identify the source as having a power-law spectrum, according to the colour-colour selection plots of Rhoads [8]. Finally, from images taken 1 day and 26 days after the burst (dominated by the optical transient and the galaxy respectively), we measure an offset of the afterglow from the host galaxy of 0.351 ± 0.049 arcsec, or 2.18 ± 0.30 kpc at the distance of the galaxy[2]. We therefore conclude that the transient is not an AGN, but rather

[1] The National Radio Astronomy Observatory (NRAO) is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. NRAO operates the VLA.
[2] We assume a standard flat cosmology with $H_0 = 65$ km s^{-1} Mpc^{-1}, $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$.

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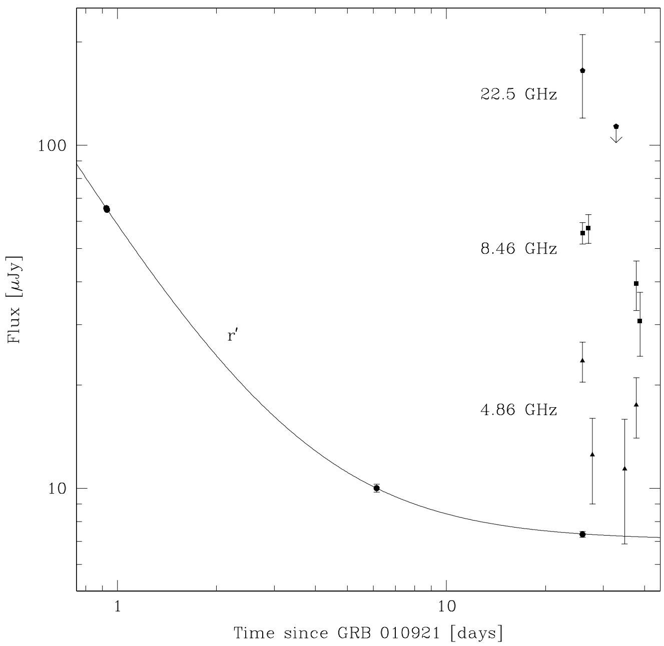

FIGURE 1. The optical and radio light curves of the afterglow of GRB 010921. The optical measurements displayed here have been corrected for Galactic extinction using $E_{(B-V)} = 0.148$. The radio measurements were multiplied by the following scale factors for presentation: 22.5 GHz 1/2; 8.46 GHz 1/4; 4.86 GHz 1/8.

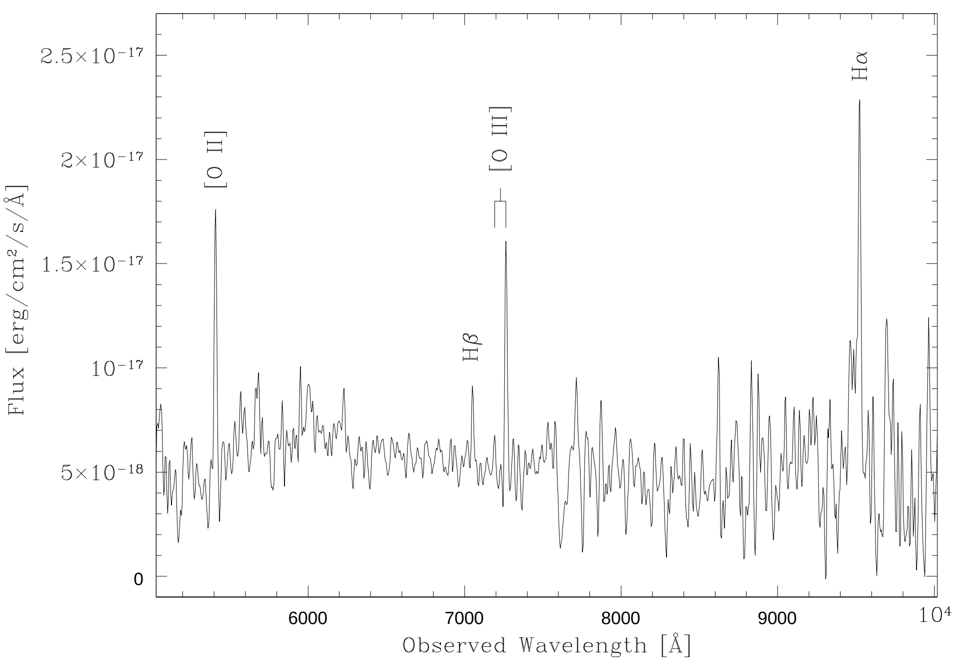

FIGURE 2. The spectrum of the host galaxy of GRB 010921. The spectrum has been smoothed with a Gaussian of FWHM = 12 Å, approximately the instrumental resolution. Emission lines corresponding to [O II], Hβ, [O III] and Hα (labelled) are clearly detected, corresponding to a mean redshift of $z = 0.45092$.

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the afterglow of GRB 010921, detected and localised by HETE-2.

Fits of a power-law temporal decay and power-law spectrum to the optical data corrected for Galactic extinction yield good fits (χ^2/DOF = 10.9/11), with $\alpha = -1.579 \pm 0.058$ and $\beta = -2.00 \pm 0.13$. Demanding that the afterglow spectral slope match that predicted from the temporal slope (e.g. Price et al. [6]) requires extinction in the source frame with $A_V > 0.4$ mag, which likely indicates that this GRB is in a dusty environment.

THE HOST GALAXY

We observed the host galaxy on 2001 Oct 17.25 with the Double Spectrograph on the Palomar 200-inch telescope. Several emission lines are detected, corresponding to [O II], Hβ, [O III] and Hα, all at a mean redshift of $z = 0.45092 \pm 0.00040$. The widths of the lines range from 10 – 13 Å, consistent with the instrumental resolution. From the observed Balmer decrement and an LMC extinction curve, we calculate A_V for the galaxy to be 1.3 mag, perhaps indicative that the extinction observed in the afterglow is due to interstellar (not circumburst) dust.

From the FREGATE 8–400 keV fluence of 1.5×10^{-5} erg/cm^2 [7], we derive the isotropic-equivalent prompt energy release as 9.0×10^{51} erg. In order for this energy to be consistent with the Frail et al. [4] relation, we would require a jet opening angle of 19°, or a jet break time at approximately 36 days after the burst, consistent with the observed light-curve.

CONCLUSION

The afterglow was discovered through the use of image differencing. The use of this technique may be a more robust method of identifying GRB afterglows than the traditional manual comparison with sky survey images, since it enables the detection of an afterglow superimposed on a bright host galaxy.

Since the afterglow of GRB 010921 is one of the most nearby afterglows, further observations of the afterglow with HST should be able to provide the most stringent limits on any supernova underlying the afterglow. And thus the HETE era begins....

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